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Valuing Interventions to Reduce Indoor Air Pollution—Fuelwood, Deforestation, and Health in Rural Nepal

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1. INTRODUCTION

Household energy use, forest and poverty are entangled in developing countries with environmental and health problems. Dependence on wood for cooking fuel generally increases the dependency of poor people on forests. This fuelwood consumption is not only linked to the forest environment, but also to the health of the inhabitants due to indoor air pollution. As the women are exposed more to the smoke pollution than the men, and children are more sensitive to it than adults, the issue of fuel is also linked with the gender and child issues.

Fuelwood is the main source of cooking energy in Nepal and will remain so for foreseeable future. About 66 percent of households use wood as the main fuel for cooking. Only about 13 and eight percent households, mostly in urban areas, use kerosene and LPG respectively. The households using biogas as the main fuel is less than two percent [CBS (2002)]. One study shows that over 89 percent of total energy use in Nepal comes from the traditional fuels [ADB (2003)]. Wood and other biomass fuels (crop residues as well as animal dung) can substitute for each other, though most consumers have a general preference for wood over other biomass [FAO (1997)]. With socio-economic development, the fuel used by a household changes to better ones in the fuel-ladder. Everybody likes to maximise their utility by choosing more convenient and prestigious fuel subject to the budget constraint. Climbing the fuel-ladder generally means stepping up from dung cakes or crop residues, fuelwood, kerosene, biogas, LPG and ultimately to the electricity. Moving to the higher steps in the ladder means better respiratory health of the family members due to lower emission.

1.1. Forest and Fuelwood

Forests in hills are environmentally very sensitive public good. Nepal initiated forest control in 1942 and nationalised all the forests in 1958 [Nepal (1956)]. Till the mid 1970s forest management was exclusively protection oriented. The people living near the

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forest were thought of the threat to the forest, because they generally dependent on forests for fuelwood, fodder and timber. The forest officials were made very powerful to control the intruders to the forest. In contrary to the expected, the deforestation continued and rather accelerated. After having denuded hills and bad shape of the forest in most parts of the country, National Forest Plan was initiated in 1976 that included the provision for utilising local people in forest management. It made provisions to hand over a part of government forests to village Panchayat, the lowest level political unit at that time.

Panchayat Forest and Panchayat Protected Forest Rule [Nepal (1978)] started the community forestry programme in Nepal. Forest lands without canopy were handed over to local political body as Panchayat Forest and forest land with tree canopy as Panchayat Protected Forest. The Panchyat was required to sow tree seeds, plant saplings, protect the forest and maintain them. But, the forests were neither handed over to actual users of the forests to feel their ownership nor were able to generate any incentive to the Panchayats to protect the valuable resource. The condition of the forest did not improve.

After the failures of national government and the Panchayats to protect the forest, a policy departure was thought. With a new strategy of involving the primary users on management Master Plan for the Forestry Sector [Nepal (1989)] was started with 25-year policy and planning framework. It aimed to meet basic needs of the local people for the forest products on a sustained basis and at the same time conserve ecosystems and genetic resources. It also aimed to protect land against degradation and contribute to local and national economy. It took the community forestry[1] as the main strategy so that all the accessible hill forests can be handed over to user groups to the extent that they are willing and capable of managing them. For implementing this plan Forest Act and Rules [Nepal (1993, 1995)] were enacted. The laws allowed handing over forest to the communities that are traditionally using them and also given substantial rights to them to manage the community forests. The community forest users groups (CFUGs) can harvest and sell forestry products from the community forest under their jurisdiction and can also exclude non-members from extracting forest products. This established a market for forest conservation. Now the forest conservation is a market activity. This led to a great success.

The degradation of forests has become a history. The success demonstrates the ingenious capacity of mostly illiterate farmers to voluntarily coordinate their actions in nurturing and utilising the forests for their own use. The laws separate rights over the forest land and over the biomass on it. The forests (other than the national parks and reserves) are classified into private and national. The term 'private forest' bears general meaning of a forest in private land. If the land belongs to the state, irrespective of whether the rights over its biomass are of the state or the community, the forest is known as national forest. The area covered by forests and protected areas like national parks, wildlife reserves, hunting reserves, conservation areas and buffer-zones is about 40 percent of the total land area of the country.

Community forest policy is still evolving with experiences being routed into the policy-making process. Forest Policy [Nepal (2000)] limited some rights of the

[1]Community forests are the parts of national forests are managed and used by local people organised as legally recognised Community Forest User Groups (CFUGs).

community of the dense forest. The government claims for 40 percent of the income from the community forests in Terai, Siwaliks and Inner Terai where the forests are dense. Large wood lots from this region will not be handed over to the community. The new policy has, however, created antagonism between the forest users in Terai and the government and it is not a good news for the forest. Now the government claim is down sized to 15 percent of the sales of the timber and not of other products alike fuelwood.

Some studies show that nearly 11 million cubic feet of timber, 338 million kilograms of fuelwood, and 371 million kilograms of grasses were harvested per annum from the community forest. A large part of the timber (3 million cubic feet) and fuelwood (2 million kilogram) are sold after meeting the internal needs and not the grass [Kanel and Niraula (2004)]. As the fuelwood harvesting from the community forest is claimed to be sustainable and the fuelwoods are also obtained from the agricultural land, the large part of fuelwood are making less harm to the forest. It is claimed that the wood energy use is not and will not be a general or main cause of deforestation [FAO (1997)]. Prime area of concern is the health of the people from the smoke generated by the biomass fuel.

1.2. Fuelwood and Health

Rural households in low-income countries cook food using traditional biomass fuels which is the major source of indoor air pollution and subsequent illnesses. Empirical evidence reports a significant relationship between exposure to indoor air pollution (IAP) and respiratory illnesses [Pandey (1984); Pandey, *et al.* (1989); Smith (2000)]. Studies also find a consistent and direct relationship between respiratory problems and domestic smoke exposure. The exposure to IAP, especially to particulate matter, from the combustion of biomass fuels (wood, charcoal, dung and agricultural residues) has been implicated as a causal agent of respiratory diseases [Chen, *et al.* (1990)]. Pollutants from biomass fuel combustion for cooking are the main source of IAP and main cause of respiratory ill health among rural people particularly to those who cook food. But, the estimates of the effects of IAP on respiratory illness obtained from the literature suffer from the problems of endogeneity [Briscoe, *et al.* (1990)]. We should not ignore that the households or individuals facing health problems may decide to change their behavior like adoption of some new technology. As a result not only the exposure to pollution affects the health but also the health problems affect the exposure leading to a problem of endogeneity. In such a case of circularity problem, estimating a single equation regression results into simultaneity bias with inefficient estimates.

Poor people decide to use biomass fuels for cooking because they are cheaper than the modern fuels and are generally easily accessible. But, the health costs can be high—a point that is generally not understood or most likely ignored. The indirect cost of solid fuel is borne in several ways, like discomfort, risk of fire and health effects. The discomforts are generally endured by the poor. The risk of fire is very small and the households consider the risk as nearly zero. The linkages to the health are not clearly visible to the less educated rural poor. Most of the time, the rural poor can not easily attribute their diseased condition to the type of stove they use or fuels they burn.

1.3. The Trade-offs

Different efforts are made to reduce the fuelwood consumption by developing alternative energy, promoting fuel switching and increasing the stove efficiency. These efforts mainly focus on comfort of the users and protection of the forest environment. Solar thermal[2] energy is used for cooking and drying.[3] Other interventions that can be mentioned are briquette production[4] from biomass like leaves, twigs, branches and agricultural and forestry residues. The briquettes are used for space heating and cooking activities in limited scale. Fuel switching to LPG is progressing in urban and semi-urban areas, but not popular in rural areas. In rural areas the households with large animals like cattle and buffalo have established biogas plants that fed animal dung. The gas is used for cooking and replaces the fuelwood to the most extent. Among the households that are still using fuelwood as the main fuel, some have constructed or even bought improved cooking stoves (ICS).[5] Different individuals value one fuel more over the others and ICS over the traditional stoves.

The individuals value forest environment as a public good and a reduction in morbidity due to respiratory health as a private good. This private value to the individual can be expressed as his or her willingness to pay (WTP) for the environmental protection and reduced morbidity. We need to find their trade-offs to estimate WTP for non-market outcomes such as environmental amenities and health.

From utility theory, we can say that people want to maximise their utility function $U = U(X, H, G)$, where, X is the vector of goods and services consumed by the household, H is the vector of health conditions and G is the vector of environmental amenities as public good. Similarly, Health Production Function $H = H(P, D, Z)$, where P is the level of indoor pollution, D is vector of risk-reducing behaviour and Z is vector of physiological and socio-economic characteristics. Under the time and budget constraints the households face, they maximise utility, implying trade-offs between market goods (X) and risk-reducing behaviour (D). The WTP for environment friendly intervention is the change in income that holds utility at the original level.

The overall goal of the study is to understand the health costs of biomass fuel use to the households. The specific objective is to estimate the health benefits of biogas and improved chula interventions that reduce the use of fuelwood leading to the protection of the forest.

2. STUDY AREA AND DATA

The study employs primary data collected from sample survey of 600 households from rural Nepal. Two districts, Syangja and Chitwan are selected purposively for the study. The Village Development Committees (VDCs), the smallest administrative units, in each district are ranked on the basis of intensity of improved cooking stoves (ICS) and

[2]Solar photovoltaic and micro-hydro are for lighting purposes than for cooking.

[3]The solar thermal units for cooking are not getting popularity due to time consuming in nature and time limitation, only available during the lunch time. Most of the farming communities in Nepal cook during morning and evening and work in the field during the day time.

[4]Among the briquettes, bee-hive briquettes are made of charred and grounded biomass mixed with clay, and are easy to ignite and does not produce much smoke.

[5]There are several types of ICS ranging from mud to metal, but for the purpose of analysis, all are assumed the same.

biogas plants. The intensity of ICS and biogas in each VDC were estimated by taking ratio of adopter households that have completed one year of adoption[6] to total number of households. From the VDCs thus ranked, three sample VDCs are selected from first 12 VDCs by using systematic sampling with random start.[7] One VDC is randomly selected from first four, and then every fourth VDC is selected. The rational behind this sampling scheme is to develop a sample of households with sufficiently large number of interventions mainly ICS and biogas for statistical analysis.[8] The lists of the households obtained from the records of the selected VDCs forms the sampling frame. The sample households in each district are allocated to select three VDCs[9] based on the probability proportionate to the number of households.

From the sampling frame from each select VDC, required number of sample households and one-fourth of replace households are selected.[10] In the survey, the actual replacement[11] of households required is less than two percent. The household survey is conducted using well structured pre-tested questionnaire. The questionnaire included modules on stove and fuel, family and respiratory diseases, costs of illness and household income.

3. METHODS

The households, given the full information, decide optimally to meet requirements of household cooking services from different fuels and maximise health status, other things remaining the same. To maximise household utility under their budget constraint they choose different stoves and fuels. The study tests two major hypotheses, (a) improved stove and biogas fuel reduce the respiratory health of the inhabitants and (b) health benefits of these interventions are larger than their market price.

3.1. Health Effects of the Interventions

For estimating the health effects of the interventions, we follow probit (probability unit) regression with dichotomous dependent variable of appearing (y=1) and not appearing (y=0) of disease symptoms. Individual health outcomes are regressed on pollution variables and individual characteristics. Fixed effect of the geographical area is

[6]Just adopted intervention may not have respiratory health effects, because cumulative effect of particulate pollution is required to cross the threshold level.

[7]Syangja district comprises of 60 VDCs and Chitwan district 37 VDCs. In addition, each district is having two municipalities too, that are not included in the sampling frame.

[8]Nepal Living Standard Survey (2003-04) shows that only two percent of the households in Nepal have biogas plant and two percent have improved cooking stove.

[9]The sample VDCs are Setidobhan (81 sample households), Sworek (125 households) and Tindobate (94 households) from Syangja district and Pithuwa (105 households), Gitanagar (125 household) and Shivnagar (70 household) from Chitwan district.

[10]The number of households in the VDCs of Syangja district is found smaller than those in the VDCs of Chitwan district. In Syangja district one household is selected randomly from first nine households, and then every ninth household is selected. Next to the first household selected and then every 36th household thereafter are selected to develop 25 percent replace households. Similarly, from the register maintained by VDCs in Chitwan district one household is selected randomly from first 20 households, then every 20th household from it is selected. Next to the first household selected and then every 80th household from it is selected to develop 25 percent replace households.

[11]The replacement is required due to non-availability of respondents even upon repeated attempts and shifting of the sample households elsewhere.

also included in the model. This model emerges from normal cumulative distribution function. The appearance of disease symptoms in *i*th individual depends on an unobservable utility index I_i. This latent variable, also known as the normal equivalent deviate (n.e.d.) or normit, is determined by one or more explanatory variables. The larger the value of the index, the greater is the probability of a disease appearing among the members of the household.

A probit model is an econometric model in which the dependent variable y_i can be only one or zero, and the continuous independent variable x_i are estimated in

$$\Pr(yi = 1) = F(xib),$$

where b is a parameter to be estimated, and F is the normal cumulative distribution function. The term '*xb*' is called the probit score or utility index. Following probit equation is estimated as the health function on pollution exposure, conditional on individual and household characteristics:

$$\Pr(Hij = 1) = \alpha + \beta 1Wj + \beta 2Aij + \beta 3Gj + eij \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where,

- *Hij* is the incidence of any respiratory disease symptom for person *i* in household *j*;
- *Wj* is a vector of smoke averting activities (stove and biogas fuels) adopted by household *j* that are endogenous;
- *Aij* is a vector of person-specific attributes (age, gender) that are truly exogenous;
- *Gj* is a geographical characteristics (hill or plain) that is truly exogenous;
- *eij* is the error term;
- a, ß1, ß2 and ß3 are the coefficients to be estimated.

3.2. Instrumentation of Endogenous Variables

The variables truly exogenous and explanatory to the health problem are identified first. Then the endogenous variables that affect health and also get affected from the health related household decisions are identified. These endogenous variables include household ownership and use of ICS and biogas and cooking hours.

The problem for estimation is that some household decisions for purchase of improved cooking stove, installation of a biogas plant, purchase of LPG may be correlated with unmeasured household and individual-specific health variables. To eliminate household un-observables, household and village fixed-effects procedure are used as instrumental variables.

A suitable instrumental variable (IV) should be valid and strong. An IV to be valid it should be truly exogenous, having no control of the household, and should have no direct effect to the dependent variable, the respiratory health. The strength of the IV is measured in terms of the statistical association with the variables instrumented. Variables having strong association with the endogenous variables are strong instruments.

Studies show that people are not passive acceptors of the risks to their health, but they adjust their behaviour because of their perceptions of their health and the risks to their health [Briscoe, *et al.* (1990)]. Several household decisions relating to the emissions of smoke pollution and the exposure of family members to that pollution may potentially be endogenous. Literature suggests an IV method, mostly employed in epidemiological studies, to address the problem [Greenland (2000); Hernan and Robins (2006)]. We attempt to identify potential instruments for this purpose.

Identification of valid and strong instrumental variables (IV) is a challenge. To be valid the IV should be exogenous to the outcome being estimated—i.e., it should not effect health directly, in this case. In addition the IV should be strong: they be directly and strongly correlated with endogenous variables that are being instrumented (*i.e.*, household IAP exposure choices). Instrumental variable estimation can be a powerful tool for avoiding the biases due to endogenous variables that are correlated with the disturbance term. But, the identification of valid and strong instrumental variables requires imagination, diligence, and sophistication [Murray (2006)]. The candidate instruments are first scrutinised intuitively, theoretically, and empirically with zero order correlation to reduce the risk of using invalid instruments. The candidate instruments are checked for weakness before using in the model.

All possible candidates for the instrumental variables are short-listed first. We intuitively selected probable candidates for instrumental variables like households characteristics (sex ratio and access to credit), land holding (irrigated land, non-irrigated land and total land), farm production (production of rice, maize), location variable (distance to the market), price variables (price of LPG, fuelwood, biogas, ICS, subsidy received for biogas), and income variables (salary income, non-agriculture income, income from crops income from livestock and total agriculture income, ratio of non-agriculture income to total income). Each of these candidates is tested for validity and strength. They are tested for their association to the health outcomes based on the validity and strength criteria discussed above. Those variables that do not affect the health outcomes are identified as valid instruments. The associations of the candidate instruments with the instrumented endogenous variables are measured to find the strength of the instruments.

For correcting the problem of endogeneity, instrumental variable regression is fitted for a probit regression model of health symptoms on exogenous variables and endogenous variables that are instrumented. The relations of air pollution variables with chronic bronchitis and asthma among the adults and ARI among the children are estimated using instrumental variable probit (ivprobit).

As the stove and fuel variables used as explanatory variables are endogenous, the ivprob[12] is used to estimate probit model. The divprob is used to find the marginal effects for ivprob. These two programmes implement Amemiya Generalised Least Squares (AGLS) estimators for probit with endogenous regressors (Newey, 1987, equation. 5.6). The endogenous regressors are treated as linear functions of the instruments and the other exogenous variables [Maddala (1983), pp. 247–252]. The Equation (1) is thus written as:

$$Pr\,(Hij = 1) = \alpha + (\beta 1Wj = IV) + \beta 2Aij + \beta 3Gj + eij \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

Where, all the symbols are as in Equation (1), except IV. The IV is a set of instrumental variables used for first step of regression and instrumented for the endogenous variables

[12]The author of the programme is Joe Harkness, Johns Hopkins University, USA, joe.harkness@jhu.edu.

Wj in the second stage. The valid and strong IV identified and used are (a) distance to the market, (b) sex ratio in the family, (c) access to the credit, (d) price of LPG, (e) year of use of biogas, (f) maize production squared, (g) ratio of income from non-agricultural sources, (h) ownership of refrigerator, and (i) ownership of television.

Though logically not related, there appear slight spurious correlations of health outcomes with two instruments, the price of the LPG and ownership of television. These two instruments are included in the model following the suggestion of Murray (2006) that "*strong instruments that are almost valid tend to incur only small biases for two-stage least squares in moderately large samples*". The price of the LPG and ownership of television are strongly correlated with the endogenous variables.

4. RESULTS AND DISCUSSION

The results are presented and discussed in this section. First, the effects of pollution reducing interventions on chronic bronchitis asthma and acute respiratory infections (ARI) are explored. Second, the health benefits of the pollution reducing interventions are estimated.

Indoor air pollution, particularly smoke pollution in the kitchen, is a life long problem for many rural residents. They are habitual to go with the problem and some of them even do not think of it as a "problem" *per se*. Those who perceive the problem do not take it seriously. There are sayings in Nepali that "where there is fire there is smoke" and "smoke does not appear without a fire". The problem in perception is evident from the fact that as high as 39 percent of the respondents reported that there is no pollution inside their kitchen. But, the actual measurement of PM_{10} level in the kitchen results that the least polluted 39 percent of the households are having average pollution level of 2,812 µg/m3 of air, which is much higher than any standard.[13] Those who reported pollution mostly blame fuelwood as the cause of pollution. This is because the uses of other polluting (dirty) fuels (like animal dung and coal) are very limited among the sample households. Likewise, electricity is not yet established as a cooking fuel in Nepal. The percent of the households using different types of cooking fuels in 600 sample households are presented in Table 1. Only two fuels, namely biogas and fuelwood are being used by more than 20 percent of the sample households. Thus the analysis is mainly based on these two major fuels.

Table 1

Statistics of Fuel Use (Dummy) for Cooking by Sample Households (n=600)

	Fuel	Mean	Percent Household Using the Fuel
1.	Fuelwood	0.965	96.5
2.	Biogas	0.283	28.3
3.	LPG	0.192	19.2
4.	Electricity	0.087	8.7
5.	Coal	0.045	4.5
6.	Kerosene	0.023	2.3
7.	Dung cake	0.018	1.8

Source: Household Survey 2005.

[13] WHO standard 150 2,812 µg/m^3 and EPA (US) standard 200 2,812 µg/m^3.

4.1. Health and Endogenous Variables and Identification of Instruments

We construct dependent variables from the reported symptoms of respiratory illnesses. The explanatory variables, both endogenous and exogenous, are identified logically and instrumental variables are screened.

4.1.1. *Symptoms of Respiratory Diseases*

Condition of chronic obstructive pulmonary disease (COPD) is a sever health problem. It is characterised by abnormalities in the lungs that make it difficult to exhale normally. Generally, two distinct diseases are involved in this case: emphysema and chronic bronchitis. Emphysema and chronic bronchitis cause excessive inflammatory processes that eventually lead to abnormalities in lung structure that permanently obstruct airflow (hence the term “chronic obstructive”). A recent study shows that adults with asthma are 12 times more likely to develop COPD than those who do not have the condition.[14] If a case of COPD, chronic bronchitis or asthma is medically identified that are taken into account. But, in rural Nepal many of the diseases go untreated or at least not properly diagnosed. We resort a survey of symptoms as a rescue in such situation of data limitation. To catch the problem of COPD we surveyed the symptoms of chronic bronchitis and asthma. Symptoms of chronic cough (cough for most days for 3 months each year) and haemoptysis (bringing up phlegm for 3 months each year) are taken as the symptoms of chronic bronchitis. Similarly, shortness of breath (dyspnea) as characterised by a need to stop for breath when walking at own pace and awaken at night by attack of shortness of breath are taken as the symptoms of asthma.

The case of acute respiratory infections (ARI) is typically popular among the children. The symptoms of the ARI surveyed include stopping to feed well by the child, the child feel abnormally sleepy or is difficult to wake, fever or low body temperature, localised chest pain and cough at first dry and painful, later productive and tenacious with rusty sputum or occasionally frank blood stained. The symptoms are surveyed on one year recall basis. The disease variables are developed on the basis of appearance of the symptoms on the individuals.

4.1.2. *Endogenous and Exogenous Variables for Health Effects Analysis*

Before going through a more specific econometric analysis the study variables and explanatory variables used in different health models are defined and explained with their descriptive statistics. The explanatory variables of respiratory diseases include cooking technology (improved cook stove) and fuel use (biogas, LPG and wood). The ICS and biogas are dummies and other two are continuous variables. These cooking technology and fuel variables are endogenous as the decision of the households for stove choice and fuel choice can be affected, in turn, by the health problems they are facing. The households facing more problems of respiratory health may decide to adopt ICS or biogas depending on their preference.

The truly exogenous variables are the personal characteristics that may affect health status like age and gender. Similarly, geographical characteristics like hill and plain can affect some of the respiratory health and are truly exogenous. The problem of

[14]http://www.pulmonologychannel.com/copd/index.shtml.

endogenous variables creates a system of simultaneous equations. Reduced form equation of two stages least square is generally used to resolve the problem. To this effect, instrumental variables are identified and employed.

4.1.3. *Validity and Strength of Instrumental Variables*

We take distance to the nearest market as one of the instrumental variables. It is not significantly correlated with study variables (chronic bronchitis, asthma and ARI). Another candidate of the IV is the sex ratio in the family which is out of the control of the household, at least in the short run, and it has no association with the study variable, it is a valid instrument. As it is moderately correlated with some of the endogenous variables, it has some strength. Using the same standards and also considering the correlation of the variables with other valid instruments, the access to the credit, price of LPG, year of use of biogas, maize production squared, non-agricultural income as percent to the total income and ownership of refrigerator and television are used as instrumental variables in the study.

The descriptive statistics of the endogenous variables, exogenous variables, instrumental variables and study variables chronic bronchitis and asthma are presented in Annex I and those for acute respiratory infections in Annex II. As not all the households are having male members, the sex ratio (female to male ratio) is missing for those households not having male members. Access to credit is a dummy at household level and 69 percent of the households report that they have easy access to the credit at the time of need. The price of LPG includes the cost incurred by the households for buying and transporting to home. The price of LPG ranges from Rs 63 to Rs 70 per kg (about one US dollar). Similarly, the maize production per household is in quintal per year. To make a valid instrument the square of the maize production is taken. Another IV is the ratio of non-farm income to the total income. On an average nearly 51 percent of the income is from non-agriculture sector and rest from agriculture sector. Around six percent of the households are having refrigerator and 48 percent with a television set. The descriptive statistics are presented separately for the grown ups and the children.

4.2. Health Effects of Stove and Fuel Choice

Effects of stove choice and fuel choice on major respiratory health problems like chronic bronchitis, asthma and acute respiratory infections (ARI) are explored in this section. The results are obtained by making corrections for endogeneity *vis-à-vis* without correction.

4.2.1. Effects of Stove and Fuels on Chronic Bronchitis

We assess the effects of indoor air pollution related variables on the appearance of the symptoms of chronic bronchitis on individual members of the households using simple probit (see results in Annex III) as well as using instrumental variable probit (Table 2). The results from simple probit that suffer the problem of endogeneity differ from the results obtained through the instrumental variable probit that correct for the problem of endogeneity.

Table 2

Effects of Fuel Use and Stove Adoption to Chronic Bronchitis

	Explanatory variables	Coefficient	dF/dx	Standard Error	z	P>|z|	x-bar	[95% C.I.	]
1	ICS plus heaters+	–1.507**	–0.092**	0.051	–2.280	0.023	0.436	–0.192	0.008
2	Biogas+	–0.276*	–0.014*	0.007	–1.900	0.058	0.313	–0.028	–0.001
3	LPG	0.013	0.001	0.001	1.440	0.150	12.175	0.000	0.002
4	Wood	–0.050	–0.003	0.003	–1.040	0.298	12.617	–0.008	0.003
5	Age	0.031***	0.002***	0.000	11.700	0.000	33.360	0.001	0.002
6	Female+	0.535***	0.032***	0.006	5.340	0.000	0.493	0.019	0.045
7	Hill+	1.042***	0.068***	0.025	3.260	0.001	0.494	0.018	0.118
8	Constant	–2.562***		Log likelihood	–449.63		LR chi2(7)	244.53	
9	Observed P		0.055	N	2720		Prob > chi2	0.000	
10	Predicted P		0.024	(at x-bar)			Pseudo R2	0.214	

Note: * significant at 10 percent level, ** significant at 5 percent level, and *** significant at 1 percent level.
(+) dF/dx is for discrete change of dummy variable from 0 to 1.
z and P>|z| are the test of the underlying coefficient being 0.
C.I. = confidence interval.

The simple probit regression shows that the chronic bronchitis significantly decreases with increases in the quantity of fuel wood consumption, whereas the ICS and biogas are not significantly reducing the health problem. The results are not logically convincing. After correcting for the problem of endogeneity, the IV probit gives logically sound results that the ICS and biogas significantly reduce the symptoms of chronic bronchitis and not by the fuelwood. For the endogenous variables, namely, ICS, biogas, LPG and fuelwood, both the coefficients and slopes increase after the corrections for the endogeneity. The sign and magnitude of the coefficients and slope of the truly exogenous variables remain the same, with an exception of hill variable. In case of hill variable, the size of coefficient increases after the correction for the endogeneity. The log likelihood ratio, chi-square value and the pseudo coefficient of multiple determinations remain the similar in both the cases. The equation explains about 21 percent of the variations in chronic bronchitis and the over all equation is statistically significant.

The results after correction for endogeneity show that the use of ICS and biogas significantly reduces the symptoms of chronic bronchitis among the residents. The ICS reduces the chronic bronchitis by over nine percent and the biogas by over one percent. The problem of chronic bronchitis is more severe in old ages. This is because of the problem of respirable particulate pollution accumulates over the years and more likely to reach to the threshold level in the old age. It is more problematic among the female. This is because the female get more exposure to the cooking stove than the male. The problem of chronic bronchitis is more severe in hill region than in plain. This is because hill dwellings have smaller windows than plain dwellings.

4.2.2. *Effects of Stove and Fuels on Asthma*

The results obtained from simple probit (see Annex IV for results) and instrumental variable probit (Table 3). Both the results show that the biogas significantly reduces the problem of asthma and the ICS has no significant effect. It is surprising to note that the use of fuelwood consistently decreases the problem of asthma under both types of modeling.

Table 3

Effects of Fuel Use and Stove Adoption to Asthma

	Explanatory Variables	Coefficient	dF/dx	Standard Error	z	P>|z|	x-bar	[95% C.I.	]
1	ICS plus Heaters+	–0.806	–0.032	0.033	–1.060	0.289	0.436	–0.097	0.032
2	Biogas+	–0.285*	–0.011*	0.006	–1.740	0.082	0.313	–0.021	0.000
3	LPG	0.010	0.000	0.000	0.940	0.348	12.175	0.000	0.001
4	Wood	–0.140***	–0.006***	0.002	–2.490	0.013	12.617	–0.010	–0.001
5	Age	0.023***	0.001***	0.000	7.760	0.000	33.360	0.001	0.001
6	Female+	0.704***	0.031***	0.006	5.670	0.000	0.493	0.020	0.043
7	Hill+	0.569	0.025	0.017	1.570	0.117	0.494	–0.009	0.058
8	Constant	–1.440**		Log likelihood	–338.09		LR chi2(7)	127.81	
9	Observed P		0.034	N	2720		Prob > chi2	0.000	
10	Predicted P		0.016	(at x-bar)			Pseudo R2	0.159	

Note: * significant at 10 percent level, ** significant at 5 percent level, and *** significance at 1 percent (+) dF/dx is for discrete change of dummy variable from 0 to 1.
z and P>|z| are the test of the underlying coefficient being 0 level.
C.I. = confidence interval.

The effect of biogas is expected as the biogas reduces the smoke emissions. But, the result of fuelwood is unexpected. It can be suspected from the effects of wood that the asthma is mainly the result of past accumulation of the exposures. In addition, the use of fuelwood gives an effect of space heating that is required more for asthma patients.

The problem of asthma increases with the increase in the age. It is more severe among the female as compared to the male. Thus the use of biogas as a cooking fuel reduces the problem of asthma illness among the rural poor. The equation explains about 16 percent variation in the asthma symptoms.

4.2.3. Effects of Stove and Fuels on Acute Respiratory Infections

We assessed the effects of stove and fuel choice on acute respiratory infections (ARI) among the children of five years and less using simple probit (see Annex V for results) and instrumental variable probit (Table 4). The use of biogas reduces the problem of ARI under both estimates, but the size of coefficients and slope increases after the

Table 4

Effects of Fuel Use and Chula on ARI among the Children (Age<=5)

	Explanatory Variables	Coefficient	dF/dx	Standard Error	z	P>|z|	x-bar	[95% C.I.	]
1	ICS plus Heaters+	0.189	0.067	0.266	0.250	0.804	0.351	–0.454	0.588
2	Biogas+	–0.427*	–0.159*	0.090	–1.820	0.069	0.244	–0.335	0.017
3	LPG	–0.004	–0.002	0.003	–0.520	0.600	13.382	–0.007	0.004
4	Wood	0.044	0.016	0.011	1.410	0.157	12.592	–0.006	0.038
5	Age	–0.120**	–0.043**	0.022	–1.930	0.054	3.191	–0.087	0.001
6	Female+	–0.206	–0.074	0.057	–1.280	0.201	0.515	–0.186	0.039
7	Hill+	–0.162	–0.058	0.141	–0.410	0.681	0.462	–0.335	0.219
8	Constant	0.566		Log likelihood	–181.97		LR chi2(7)	14.34	
9	Observed P		0.671	N	299		Prob > chi2	0.046	
10	Predicted P		0.678	(at x-bar)			Pseudo R2	0.038	

Note: * significant at 10 percent level, ** significant at 5 percent level, and *** significance at 1 percent level.
(+) dF/dx is for discrete change of dummy variable from 0 to 1.
z and P>|z| are the test of the underlying coefficient being 0.
C.I. = confidence interval.

adjustment. The use of biogas as a cooking fuel reduces the problem of ARI nearly by a half (43 percent). The LPG reduces the ARI and fuelwood increases that before making the adjustment. But, after the adjustment for the endogeneity neither LPG nor fuel wood is significant.

The problem of ARI decreases with increase in age. The problem is not significantly different for girls and boys, and in hill and plain. The use of ICS is not affecting the problem of ARI among the children. The coefficient of multiple determinations (pseudo R^2) decreases after making the adjustment for the endogeneity. The equation after adjustment explains about four percent of the variations in ARI and the equation is statistically significant. The only policy variable available to reduce the problem of ARI is the biogas.

4.3. Health Benefits of Improved Stove and Biogas

The costs of illnesses are estimated for chronic bronchitis, asthma and ARI directly from the survey of the cost incurred by the households on suffering individuals (Table 5). The cost of chronic bronchitis is estimated to be Rs 2,866 that includes the treatment costs and opportunity costs of time.[15] The cost of asthma is Rs 2,374 and that of ARI Rs 4,513. The major chunk (over 70 percent) of these costs goes to the costs of medicine. Around four percent goes to the fees of doctors and hospitals. The costs of diagnostic tests are still lower. The opportunity costs of the time lost due to travelling to hospitals/health posts, stay in hospitals/health posts, un-ability to work and the time of caretakers lost (see Annex VI for detail) ranges from about nine percent in ARI to 19 percent in asthma. If we can reduce the probability of these diseases the costs of the illnesses can be reduced that increases the welfare of the households.

Table 5

Costs of Illnesses

			Chronic Bronchitis		Asthma		ARI	
	Cost Headings	Unit	Rs	%	Rs	%	Rs	%
1	Medicine Costs	Rs	2,107.5	73.5	1,706.0	71.9	3,604.2	79.9
2	Laboratory Costs (X-ray, cough test etc.)	Rs	64.3	2.2	57.0	2.4	173.4	3.8
3	Hospital/Doctor Fees	Rs	104.1	3.6	92.0	3.9	224.9	5.0
4	Travel Costs to and from for the treatments	Rs	43.9	1.5	41.9	1.8	88.1	2.0
5	Additional dietary expenses resulting from illness	Rs	19.0	0.7	18.0	0.8	31.4	0.7
6	Opportunity cost of time lost	Rs	527.5	18.4	458.8	19.3	391.2	8.7
	Total Costs of Illness (A+B)	Rs	2,866.3	100.0	2,373.7	100.0	4,513.2	100.0

Source: Household Survey 2005.

We estimate the reduction in the health costs per intervention of stove and biogas based on the reduction in the health problems of chronic bronchitis, asthma and ARI by these interventions and costs of these illnesses. It is found that the ICS plus heaters reduce health costs by Rs 264 per person per annum (Table 6), leading to a reduction of Rs 1,354 per household (Table 7). Taking the average life of ICS plus heaters as 10 years, one stove reduces the health costs of rural people by Rs 13,537. This benefit is more than 22 times of the average price of the stove.

[15]This is the cost of morbidity. The costs of pain and sufferings, and that mortality are excluded due to problem in estimation.

Table 6

Health Benefits of Intervention

	Particulars	Unit	IAP Reducing Intervention: ICS Plus Heaters	IAP Reducing Intervention: Biogas
1	Change in chronic bronchitis	dF/dx	–0.092	–0.014
2	Change in asthma	dF/dx	0	–0.011
3	Change in ARI	dF/dx	0	–0.159
4	Reduction in costs of chronic bronchitis	Rs	–263.7	–40.13
5	Reduction in costs of asthma	Rs	0	–26.11
6	Reduction in the costs of ARI for those households (217) having children	Rs	0	–717.60
	Average reduction in the costs of ARI for 600 households		0	259.53
7	Total reduction in respiratory health costs	Rs	-263.7	-325.77

Table 7

Costs of the Interventions and Their Health Benefits per Household

	Variable	Unit	n	Mean	Standard Deviation	Minimum	Maximum
1	Price of ICS plus heater	Rs	370	604.85	504.07	60	4,000
2	Price of biogas	Rs	170	19,614.71	4251.01	11000	35,000
3	Health benefits from ICS plus heaters	Rs	600	1,353.66	492.49	264	2,637
4	Health benefits from biogas	Rs	600	698.83	549.17	66	3,202

The biogas is found to reduce the health costs by Rs 326 per person per year. For an average household this benefit is Rs 699 per year. Taking a reasonable life of 30 years of a biogas plant the total benefits per plant comes to be Rs 20,965. This health benefit is more than the average costs of biogas plant.

The households invest in pollution reducing interventions on the basis of the costs and benefits they perceive. The full cost (minus subsidy, if any) is perceived by the rural households. But, not all the benefits, particularly the health benefits that are indirect, are known to them. There is a need to make the rural households aware about the health benefits of the intervention so that larger proportion of the rural households can adopt the intervention and the health can be saved.

5. CONCLUSIONS

The analysis started with the development of community forestry in Nepal and its relevance to fuelwood supply. Then the relation of fuelwood to the health through the path of smoke that cause indoor air pollution is explored. The effects of indoor air pollution to the health outcomes are assessed for chronic bronchitis, asthma and ARI. It is difficult to locate a medically identified case of such diseases from household samples. In rural Nepal many of the diseases go untreated or at least not properly diagnosed. The visible symptoms of these diseases are surveyed.

Symptoms of chronic cough and haemoptysis are taken as the symptoms of chronic bronchitis and shortness of breath or dyspnoea as the symptoms of asthma. Symptoms of ARI are surveyed for the children of age five year and less. The explanatory variables included are cooking technology and fuel, personal characteristics like age and gender. The variables are categorised into two- endogenous and truly exogenous. The endogenous variables identified are ICS plus heaters, biogas, LPG and fuel wood. The endogenous variables are instrumented by a set of valid and relatively strong instruments.

We assess the effects of indoor air pollution related variables on the appearance of the symptoms of chronic bronchitis on individual members of the households using simple probit as well as with instrumental variable probit. The results from two types of analysis are found to be different. The simple probit regression results into a conclusion that improved stoves and biogas do not reduce the problem of chronic bronchitis, whereas the instrumental variable probit shows that the improved stoves and biogas significantly reduces the chronic bronchitis.

For the asthma and ARI, the results from two types of regression differ in magnitude of the coefficients and slope. Such differences in results are due to the problem of endogeneity. The results obtained after correcting for endogeneity using IV probit gives more reliable results that in addition age and gender, the use of improved stove and biogas significantly reduces the respiratory health problems.

The problem of respiratory health is more severe at the older age particularly those who are female. As the cooking is generally done by the female, they suffer more from the respiratory problems. They need special attention of health workers and development partners that attempt to reduce the health effects of indoor air pollution.

Promotion of the improved *chula* and biogas in the rural areas can help to save the rural people from the respiratory health problem arising due to indoor air pollution. An improved stove can reduce health costs by Rs 1,354 per year. This benefit is several times higher than the market price of the improved stove. A biogas is found to reduce the health costs by Rs 699 per year. For the entire life of the biogas, the health benefit is higher than the average costs of construction of a biogas plant.

The households invest in pollution reducing interventions on the basis of the costs and benefits they perceive. The health benefits of improved stove and biogas are not adequately perceived by the rural people. There is a need to make the rural households aware about the health benefits of the intervention so that larger proportion of the rural households can adopt the intervention and the health can be saved. At the same time it saves the forest from harvesting for fuelwood. It is easier to convince the people about their price costs due to the health problem from fuelwood than convincing them for the improvement of the public good, the forest environment. Some hard core poor may not have enough animals for a biogas plant. For this case improved chula may help. The results lead us to a conclusion that not only the internalisation of the externality but also exploration of the hidden internal costs can be instrumental to reduce the public bad.

ANNEXES

Annex I

Statistics of Endogenous, Exogenous and Instrumental Variables for Adults

Variable	Unit	N	Mean	Standard Deviation	Minimum	Maximum
Endogenous Variables						
1 ICS plus heaters	incidence	2739	0.44	0.50	0	1
2 Biogas	incidence	2739	0.31	0.46	0	1
3 LPG	kg/year	2739	12.11	28.70	0	170.4
4 Wood	qt/year	2739	12.64	6.45	0	62.4
Exogenous Variables						
5 Age	year	2739	33.42	17.38	11	95
6 Female	yes/no	2739	0.50	0.50	0	1
7 Hill	yes/no	2739	0.50	0.50	0	1
Instrumental Variables						
8 Distance to the market	minutes	2739	41.38	21.01	1	60
9 Sex ratio in the household	ratio	2723	1.18	0.87	0	9
10 Access to credit	yes/no	2739	0.69	0.46	0	1
11 Price of LPG	Rs/kg	2739	66.37	1.54	63.38	70.42
12 Year of use of biogas	year	2739	2.03	3.70	0	17
13 Maize production squared	qt	2739	45.21	217.61	0	3600
14 Ratio of income from non-agricultural sources	%	2736	50.72	31.51	0	100
15 Refrigerator	incidence	2739	0.06	0.23	0	1
16 Television	incidence	2739	0.48	0.50	0	1
Study Variables						
17 Chronic bronchitis	incidence	2739	0.055	0.228	0	1
18 Asthma	incidence	2739	0.034	0.181	0	1

Annex II

Statistics of Endogenous, Exogenous and Instrumental Variables for Children

Variable	Unit	n	Mean	Standard Deviation	Minimum	Maximum
Endogenous Variables						
1 ICS plus heaters	incidence	301	0.35	0.48	0	1
2 Biogas	incidence	301	0.25	0.43	0	1
3 LPG	kg/year	301	13.29	33.88	0	170.4
4 Wood	qt/year	301	12.66	6.89	0	43.2
Exogenous Variables						
5 Age	year	301	3.20	1.40	1	5
6 Female	yes/no	301	0.52	0.50	0	1
7 Hill	yes/no	301	0.47	0.50	0	1
Instrumental Variables						
8 Distance to the market	minutes	301	40.79	21.94	1	60
9 Sex ratio in the family	ratio	299	1.32	1.09	0.2	9
10 Access to credit	yes/no	301	0.64	0.48	0	1
11 Price of LPG	Rs/kg	301	66.18	1.67	63.38	70.42
12 Year of use o biogas	year	301	1.37	3.21	0	16
13 Maize production squared	qt	301	25.75	82.14	0	900
14 Ratio of income from non-agricultural sources	%	301	52.5.5	31.93	0	100
15 Refrigerator	incidence	301	0.06	0.23	0	1
16 Television	incidence	301	0.49	0.50	0	1
Study Variable						
17 ARI	incidence	301	0.671	0.471	0	1

Annex III

Effects of Fuel Consumption and Chula on Chronic Bronchitis (Age >10 Years)— Without IV

	Explanatory Variables	Coefficient	dF/dx	Standard Error	Z	P>|z|	x-bar	[95% C.I.]	
1	Improved cook stoves+	–0.103	–0.006	0.007	–0.910	0.362	0.437	–0.019	0.006
2	Biogas+	–0.049	–0.003	0.006	–0.500	0.615	0.313	–0.014	0.008
3	LPG	–0.002	–0.0001	0.000	–0.850	0.398	12.112	0.000	0.000
4	Wood	–0.023***	–0.001***	0.001	–2.640	0.008	12.642	–0.002	0.000
5	Age	0.031***	0.002***	0.000	12.730	0.000	33.417	0.002	0.002
6	Female+	0.525***	0.032***	0.006	5.480	0.000	0.495	0.020	0.044
7	Hill+	0.426***	0.026***	0.007	4.090	0.000	0.497	0.013	0.038
8	Constant	–3.100***		Log likelihood	–457.23		LR chi2(7)	248.59	
9	Observed P		0.055	n	2739		Prob > chi2	0.000	
10	Predicted P		0.025	(at x-bar)			Pseudo R2	0.214	

(+) dF/dx is for discrete change of dummy variable from 0 to 1.
z and P>|z| are the test of the underlying coefficient being 0.

Annex IV

Effects of Fuel Consumption and Chula on Asthma (Age >10 Years)—Without IV

	Explanatory Variables	Coefficient	dF/dx	Standard Error	z	P>|z|	x-bar	[95% C.I.]	
1	Improved cook stoves+	–0.111	–0.005	0.005	–0.830	0.404	0.437	–0.015	0.006
2	Biogas+	–0.204*	–0.008*	0.004	–1.760	0.078	0.313	–0.016	0.000
3	LPG	–0.002	–0.0001	0.000	–0.940	0.350	12.112	0.000	0.000
4	Wood	–0.030***	–0.001***	0.000	–2.890	0.004	12.642	–0.002	0.000
5	Age	0.024***	0.001***	0.000	8.660	0.000	33.417	0.001	0.001
6	Female+	0.676***	0.030***	0.005	5.760	0.000	0.495	0.019	0.041
7	Hill+	0.195*	0.008*	0.005	1.640	0.101	0.497	–0.002	0.018
8	Constant	–2.838***		Log likelihood	–339.40		LR chi2(7)	133.20	
9	Observed P		0.034	n	2739		Prob > chi2	0.000	
10	Predicted P		0.017	(at x–bar)			Pseudo R2	0.164	

(+) dF/dx is for discrete change of dummy variable from 0 to 1.
z and P>|z| are the test of the underlying coefficient being 0.

Annex V

Effects of Fuel Consumption and Chula on ARI among the Children (Age <=5 Years)—Without IV

	Explanatory Variables	Coefficient	dF/dx	Standard Error	z	P>|z|	x-bar	[95% C.I.]	
1	Improved cook stoves+	0.204	0.072	0.080	0.890	0.374	0.352	–0.084	0.228
2	Biogas+	–0.369**	–0.137	0.067	–2.100	0.036	0.246	–0.268	–0.006
3	LPG	–0.007**	–0.002	0.001	–2.220	0.027	13.293	–0.005	0.000
4	Wood	0.023**	0.008	0.004	1.980	0.047	12.658	0.000	0.016
5	Age	–0.127**	–0.045	0.020	–2.280	0.023	3.199	–0.084	–0.006
6	Female+	–0.207	–0.074	0.055	–1.340	0.180	0.518	–0.181	0.034
7	Hill+	–0.178	–0.064	0.067	–0.960	0.337	0.465	–0.195	0.067
8	Constant	0.877***		Log likelihood	–180.04		LR chi2(7)	21.23	
9	Observed P		0.671	n	301		Prob > chi2	0.003	
10	Predicted P		0.679	(at x-bar)			Pseudo R2	0.056	

(+) dF/dx is for discrete change of dummy variable from 0 to 1.
z and P>|z| are the test of the underlying coefficient being 0.

Annex VI

Costs of Illness

	Cost Headings	Unit	Chronic Bronchitis	Asthma	ARI
1	Medicine Costs	Rs	2,107.5	1,706.0	3,604.2
2	Laboratory Costs (X-ray, cough test etc.)	Rs	64.3	57.0	173.4
3	Hospital/Doctor Fees	Rs	104.1	92.0	224.9
4	Travel Costs to and from for the treatments	Rs	43.9	41.9	88.1
5	Additional dietary expenses resulting from illness	Rs	19.0	18.0	31.4
A	**Total Cash Expenses**	**Rs**	**2,338.8**	**1,914.9**	**4,122**
1	Time spent on travelling	hour	1.7	1.4	6.6
2	Time spent on health post or hospital	hour	21.1	20.1	8.9
3	Work hours lost due to illness	hour	12.1	9.6	0.0
4	Time spent by caretakers	hour	7.3	5.6	26.4
5	Total time lost due to illness	hour	42.2	36.7	31.3
B	**Opportunity Cost of Time (@Rs 100/8 Hours)**	**Rs**	**527.5**	**458.8**	**391.2**
	Total Costs of Illness (A+B)	**Rs**	**2,866.3**	**2,373.7**	**4,513.2**

Source: Household Survey 2005.

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